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CANMET
Canada Centre for Mineral and Energy Technology
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POSSIBLE TECHNOLOGIES FOR THE EXPLOITATION OF DOMESTIC MANGANESE RESOURCES

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SUMMARY

Information is compiled on manganese use and trade in Canada. Several processes are examined for producing manganese products from domestic resources. Capital and operating cost estimates are prepared to show the economics of each process.

Extracting manganese values from domestic, low-grade manganese ores for the production of ferromanganese is not considered to be economic. Producing manganese metal and battery-grade manganese dioxide from domestic and imported ores with the Modified Sulphatization - Lime Neutralization process could be economically viable. The production cost of manganese metal and battery-grade manganese dioxide from domestic ore containing 14% manganese is estimated at $1,159 and $691 per tonne respectively.

If the sulphatization plant was built adjacent to a non-ferrous smelter, concentrated SO_2 off-gases could be used for sulphatization. The end result would be: reduced SO_2 emissions and lower operating costs for the sulphatization plant.

Although capital and operating cost estimates for the production of different manganese products are based on the Woodstock, N.B. deposit, the process recommended is equally applicable to manganese deposits found elsewhere in Canada. The capital and operating costs would differ from ore to ore, depending mainly on the manganese content of the source material.

Since manganese metal and battery-grade manganese dioxide are imported by Canada, the possibility of producing both commodities domestically should be examined. At present there is no research program at CANMET related to the extraction of manganese from domestic ores. It is recommended therefore that a research program be initiated to determine the technical and economic viability of extracting manganese from domestic sources using the Modified Sulphatization - Lime Neutralization process for the production of manganese and battery-grade manganese dioxide.

RÉSUMÉ

On a compilé l'information sur les emplois et le commerce du manganèse au Canada. On an examiné plusieurs procédés de fabrication de produits dérivés du manganèse provenant des ressources domestiques de ce métal. On a préparé des estimations des coûts en capital et d'exploitation, pour indiquer la rentabilité économique de chaque procédé.

L'extraction du manganèse à partir de minerais de manganèse domestiques et de faible teneur pour la production de ferromanganèse n'est pas économiquement rentable. La production de manganèse sous forme métallique et de bioxyde de manganèse convenant à la fabrication de batteries, à partir de minerais domestiques et importés, par le procédé modifié de sulfatation et de neutralisation par la chaux pourrait être économiquement viable. À partir de minerai d'une teneur de 14%, on estime respectivement à $1,159 et $691 par tonne le coût de production du manganèse sous forme métallique et du bioxyde de manganèse convenant à la fabrication de batteries.

Si l'on construisait l'usine de sulfatation à proximaté d'un four de fusion pour minerais non ferreux, on pourrait se servir du SO_2 concentré, libéré sous forme de gaz de cheminée, pour effectuer la sulfatation. Le résultat final serait: une réduction des émissions de SO_2 et des coûts d'exploitation pur l'usine de sulfatation.

Bien que les estimations des coûts en capital et d'exploitation concernant la production de divers produits à base de manganèse s'applique au minerai de Woodstock au Nouveau-Brunswick, le procédé recommandé convient également aux minerais de manganèse trouvés ailleurs au Canada. Les coûts en capital et d'exploitation différeraient d'un minerai à l'autre, surtout suivant le teneur en manganèse du minerai.

Puisque le manganèse métallique et le bioxyde de manganèse convenant à la fabrication de batteries sont importés par le Canada, on doit envisager la possibilité de fabriquer ces deux produits sur place.

Actuellement, il n'existe au CANMET aucun programme de recherche sur l'extraction du manganèse à partir de minerais domestiques. Par conséquent, on recommande de lancer un programme de recherche pour déterminer la viabilité technique et économique des techniques d'extraction du manganèse à partir de sources domestiques, en particulier du procédé modifié de sulfatation et de neutralisation par la chaux, qui donnerait du manganese métallique et du bioxyde de manganèse convenant à la fabrication de batteries.

INTRODUCTION

Manganese is an important raw material for the production of steel and other products. At present all of the manganese consumed in Canada is imported.

The purpose of this report is to identify mineable domestic manganese resources and evaluate potential processes for the production of manganese products which could economically compete with manganese imports or which might be needed to replace some of the imports during a period of supply interruption.

MANGANESE CONSUMPTION IN CANADA

Manganese is an essential ingredient in the production of nearly all types of steel and approximately 95% of all manganese produced is consumed by the iron and steel industry. Accordingly, the demand for manganese is essentially determined by the world production of iron and steel. Table 1 shows Canadian manganese imports, exports and consumptions for the years 1970, 1975-80. In addition to manganese ore, ferromanganese and silicomanganese, Canada also imports manganese metal, battery-grade manganese dioxide and other manganese products. These latter products are not shown in Table 1.

The approximate value of imports and exports for different manganese products for the years 1979-1980 is shown in Table 2.

It is interesting to note that a reduction in import of manganese ore is always accompanied by an increase in ferro- and silicomanganese imports. Since battery-grade manganese dioxide is independent of the state of the steel industry, its import does not fluctuate but shows a slight increase every year.

TABLE 1

CANADIAN MANGANESE IMPORTS, EXPORTS AND CONSUMPTION, 1970, 1975-80(1)

	IMPORTS			EXPORTS	CONSUMPTION	
	Manganese Ore[1]	Ferro-Manganese	Silico-Manganese	Ferro-Manganese	Ore	Ferromanganese and Silicomanganese
	(gross weight, tonnes)					
1970	115 052	17 891	975	510	153 846	97 952
1975	69 773	35 701	5 732	1 168	160 976	95 869
1976	118 972	25 098	12 056	9 861	238 629	83 687
1977	57 644	29 404	4 835	23 104	182 157	82 467
1978	136 446	26 812	15 842	19 924	201 320	69 349
1979	45 150	83 700	21 877	12 043	64 699	89 429
1980 P	95 161	26 704	20 902	11 278	..	..

Source: Energy, Mines and Resources Canada; Statistics Canada.

[1] Mn content.

P Preliminary; .. Not available.

TABLE 2

CANADA, MANGANESE, TRADE AND CONSUMPTION, 1979 AND 1980(1)

	1979		1980P	
	(tonnes)	($000)	(tonnes)	($000)
Imports				
Manganese in Ores and Concentrates				
Gabon	9 552	1,479	36 346	6,577
South Africa	-	-	23 508	2,994
Brazil	10 996	1,832	15 360	2,977
United States	5 182	1,889	8 010	2,590
Fr. Africa, nes	18 935	2,970	11 937	2,432
Other countries	485	177	-	-
Total	**45 150**	**8,437**	**95 161**	**17,570**
Manganese Metal				
South Africa	7 811	8,326	6 413	7,775
United States	246	212	440	690
Other countries	217	311	103	136
Total	**8 274**	**8,849**	**6 956**	**8,601**
Ferromanganese, including Spiegeleisen[2]				
South Africa	22 129	12,366	12 284	5,946
Norway	5 042	3,307	9 468	5,103
United States	19 505	11,809	4 792	3,777
France	68	84	102	133
Sweden	-	-	36	69
Mexico	794	338	20	10
West Germany	-	-	2	1
Brazil	10 500	5,118	-	-
Other countries	25 662	12,269	-	-
Total	**83 700**	**45,291**	**26 704**	**15,039**
Silicomanganese, including Silicospiegeleisen[2]				
United States	12 080	7,054	12 089	7,995
Norway	6 776	3,552	4 050	2,430
Other countries	3 021	1,740	4 763	3,013
Total	**21 877**	**12,346**	**20 902**	**13,438**
Exports				
Ferromanganese[2]				
United States	11 962	2,767	11 189	3,753
Malaysia	-	-	53	29
Jamaica	81	63	-	-
Other countries	-	-	36	20
Total	**12 043**	**2,830**	**11 278**	**3,802**
Consumption				
Manganese Ore				
Metallurgical grade	61 643	..	..	..
Battery and chemical grade	3 056	..	..	..
TOTAL	**64 699**	..	..	..

Source: Statistics Canada; Energy, Mines and Resources Canada.

[1] Mn contents; [2] Gross weight.

P Preliminary; - Nil; .. Not available; nes Not elsewhere specified.

Principal Manganese Products

Manganese Metal

Manganese is often added to speciality steels as metal to increase strength and hardness. The HADFIELD steels, a type of specialty steel, contain between 10 and 14% manganese. They are extremely hard and tough and are suited for use where severe mechanical conditions are encountered, such as in rock crusher parts or in the teeth of earth moving machinery. Manganese is also alloyed with non-ferrous metals. Aluminum-manganese alloys are noted for their strength, hardness and stiffness; manganese-magnesium alloys are hard, stiff and corrosion resistant; and manganese-bronzes are used in the production of ship's propellers.

Manganese metal is manufactured by both aqueous and fused salt electrolysis processes. There is no manganese metal producer in Canada and all manganese metal requirements are imported. Annual manganese metal import is around 8-9 thousand tonnes with an approximate value of $8-9 million.

Ferromanganese

The excellence of manganese as a desulphurizer makes it irreplacable in the steel industry. Steels containing excess sulphur are not homogeneous and tend to crack and tear during rolling and forming. Added manganese combines with the sulphur and produces a manganese sulphide slag which is readily separated from the steel. Manganese also acts as a deoxidizer during the manufacture of steel.

Manganese is commonly added as a ferroalloy during the making of steel. The largest tonnage of manganese addition alloy used in the steel industry is in the form of standard ferromanganese (also known as high carbon ferromanganese). Steel manufacturers in Canada add about 5.8 kilograms of manganese per tonne of crude steel produced.

Until recently, most high carbon ferromanganese used by the steel industry was produced in a blast furnace process similar to that used for the production of iron. The balance was produced in electric furnaces. Since 1978, the production of high carbon ferromanganese by the blast furnace method has been discontinued in the United States and Japan and is rapidly declining in Europe. Table 3 gives specifications for manganese ferroalloys; Table 4 shows typical operating data for a large electric furnace producing high carbon ferromanganese.

In Canada, Union Carbide Ltd. and Chromasco Ltd. both with plants located at Beauharnois, Quebec are producers of ferro- and silicomanganese. Manganese ore required for their operation is imported from Garbon, South Africa, Brazil and the U.S. Union Carbide's operating capacity is 120,000 tonnes/year of standard ferromanganese (3). Chromasco Ltd.'s operating capacity is around 25,000 tonnes/year of high carbon ferromanganese.

Although, the two ferromanganese producers could satisfy domestic demand for standard ferromanganese a considerable amount of ferromanganese alloy is still imported. Domestic consumption of standard ferromanganese was estimated at 89,000 tonnes/year in 1979.

Silicomanganese

Silicomanganese is an alloy of manganese and iron that contains 12.5-18.5 silicon. As shown in Table 3, it is available in various grades. Its main use is as a deoxidant in the steel industry and in the manufacture of acid resisting alloys. The smelting process used in producing silicomanganese is similar to electric furnace smelting of standard ferromanganese. The charge to the furnace contains large amounts of quartz and, if required, limestone and dolomite to adjust slag composition. Power requirements range from 4.1-5.1 Mwh per tonne of alloy, depending on the quality of the ore and on the silicon content of the alloy.

Union Carbide Ltd. has a production capacity of approximately 60,000 tonnes silicomanganese alloy per year. Chromasco Ltd. production capacity is 25,000 tonnes silicomanganese per year. Domestic sale of the alloy is approximately 30,000 tonnes/year (3).

TABLE 3

SPECIFICATIONS AND TYPICAL COMPOSITIONS OF MANGANESE FERROALLOYS, % (2)

ALLOY	Mn	C max	Si max	P max	S max	As max	Fe	Pb max
Ferromanganese								
high carbon								
Grade A	78-82	7.5	1.2	0.35	0.05	0.30	7.8-11.8	0.050
Grade B	76-78	7.5	1.2	0.35	0.05	0.30	11.8-13.8	0.050
Grade C	74-76	7.5	1.2	0.35	0.05	0.30	13.8-15.8	0.050
typical commodity grade	78-80	6.7	0.7	0.30	0.04	0.25	12-14	0.050
medium carbon								
regular grade	80-85	1.5	1.5	0.30	0.02	0.15	11-16	0.050
MS grade	80-85	1.5	0.35	0.30	0.02	0.15	11-16	0.050
low carbon	85-90		2.0	0.20	0.02	0.10	7-12	0.020
Silicomanganese	65-68	2.00	16.0-18.5	0.20	0.04	0.10	10.5-16	0.030
Ferromanganese-Silicon	63-66	0.08	28-32	0.05	0.04	0.15	1-8	0.050

TABLE 4

TYPICAL OPERATING DATA H.C. FeMn FURNACE, 3-1.9 m (diameter) Electrodes (a) (2)

	VALUE
operating load, MW	30-35
apparent power, MVA	58.9-61.6
power factor	0.51-0.57
electrode current, kA	130
single-phase resistance, m	0.592-0.690
secondary voltage, V	262-274
corrective capacitors for 0.95 power factor, MVAr	32.3
High Mn slag practice:	
usage per t alloy	
Mn ore, t dry	1.969
coke, t dry	0.417
electrode paste, kg	8.0
power, kwh	2200
ratio, slag to alloy	0.45
alloy composition, %	
Mn	79.0
Fe	13.0
Si	0.3
C	6.7
slag composition, %	
MnO	38.7
SiO_2	24.7
Al_2O_3	14.4
CaO	13.0
MgO	2.7
Mn recovery	
alloy	83.2
slag	13.8
fume, etc.	3.0

(a) Assuming single-phase reactance=1.0m OHM.

Battery-Grade Manganese Dioxide

One of the non-metallurgical uses of manganese is in the form of manganese dioxide in dry cell batteries where it serves as a source of readily available oxygen. Natural manganese ores used in batteries must grade above 85% manganese dioxide and must have a low iron content. Since very few natural manganese dioxide ores are suitable for battery purposes, most batteries contain a blend of natural ore and synthetic manganese dioxide.

Commercial Manganese Compounds

a) Manganese Carbonate
b) Manganese Sulphate
c) Manganese Chloride
d) Manganese Nitrate
e) Manganese Oxide (MnO)
f) Chemical Manganese Dioxide (CMD)
g) CMD Hydrate Type 1
h) CMD Hydrate Type 2.

All the above manganese compounds are made from water soluble manganese salts, manganese (II) oxide or hydroxide.

For the most part, the above compounds are used as fertilizer additives or as a starting materials for the production of potassium permanganate, high purity MnO_2 (Faradizer) for batteries, etc. Most of the above compounds are also imported.

Manganese Ores

Metallurgical grade manganese ores contain more than 35% manganese and are used to produce both low and high grade manganese ferromanganese. Battery-grade naturally occuring ores are included in this class; however, battery-grade ores must contain no less than 85% manganese dioxide. Table 5 shows chemical analyses of some of the most important manganese ores in the world.

TABLE 5

ANALYSES OF MANGANESE ORES (a) USED IN NONMETALLURGICAL APPLICATIONS OR MANUFACTURE OF Mn CHEMICALS, WT.% (2)

CONSTITUENT	1	2	3	4	5	6	7
Mn (total)	55.42	54.85	51.4	52.30	48.85	30.81	30-35
MnO_2	85.9	83.64	74.0	78.30	70.99	nil	
MnO	1.51	3.04	5.99	3.62	5.16	39.77	
Fe (total)	0.53					1.04	2-3
Fe_2O_3	0.76	2.64	3.16	3.13	7.55		
S	0.012	0.101		0.006		0.04	
P	0.039	0.08	0.140	0.095	0.081	0.06	
Cu	0.21	0.03	0.05	0.0089	0.036	trace	
Pb	0.98		0.02	0.025	0.025	trace	0.1-0.2
Co		0.095	0.01	0.0193	0.054		0.1
Ni		0.05	0.07	0.0210	0.092		0.1
SiO_2	4.28	1.06	3.81	2.62	2.93	12.68	15-20
Al_2O_3	0.86	4.67	5.42	3.00	4.52	2.15	
CaO + MgO	0.78	0.05	0.1	0.105	0.08	8.25	
BaO	2.37	0.37	0.15	2.34	0.28	trace	
$K_2O + Na_2O$	0.42	0.61	1.66	0.89	1.89	0.175	
CO_2		0.41		0.33	0.67	33.68	

(a)
1. Imini Mine, Morocco;
2. Moanda Mine, Gabon;
3. Kisenge, Zaire, Congo;
4. Groote Eylandt, Australia
5. Amapa Brazil
6. Ghana (N-grade carbonate)
7. Japan (High-grade carbonate)

MARKET PRICES FOR DIFFERENT MANGANESE PRODUCTS

In order to appreciate the value of each manganese product, a reasonably current price list for a selected number of manganese products is shown in Table 6.

DOMESTIC MANGANESE ORE DEPOSITS

Several low-grade manganese deposits have been identified in Nova Scotia, New Brunswick, Ontario and Quebec. Table 7 shows the low-grade manganese ore deposits across the country with their estimated reserves and approximate chemical compositions. It is outside the scope of this report to investigate each deposit in detail, therefore the Woodstock, N.B. deposit was chosen, arbitrarily, to demonstrate the viability of different processes to produce manganese products from domestic sources.

EXTRACTION OF MANGANESE VALUES FROM LOW-GRADE MANGANESE ORES

Low-grade manganese ores are not amenable to physical beneficitation processes such as, gravity or magnetic separation or flotation treatment. Several chemical dissolution techniques have been used to successfully extract manganese from low-grade ores but all these processes have proved to be uneconomic even with very low energy prices. Figure 1 is a simplified flowsheet summarizing all the processes examined for upgrading low-grade manganese ores for the production of manganese oxides[4].

Table 8 is a listing of nearly all the processes shown in Figure 1. A detailed evaluation of each process is outside the scope of this report as the total number of process combinations, shown in Figure 1, is around 40. Therefore the most important parameters (Capital, Energy, Reagent and Environmental costs) are rated in the table for each process. The process using calcium dithionate and calcium hydroxide to precipitate $Mn(OH)_2$ from manganeous sulphate is omitted from Table 8 because it is not considered to be technically or economically viable.

TABLE 6

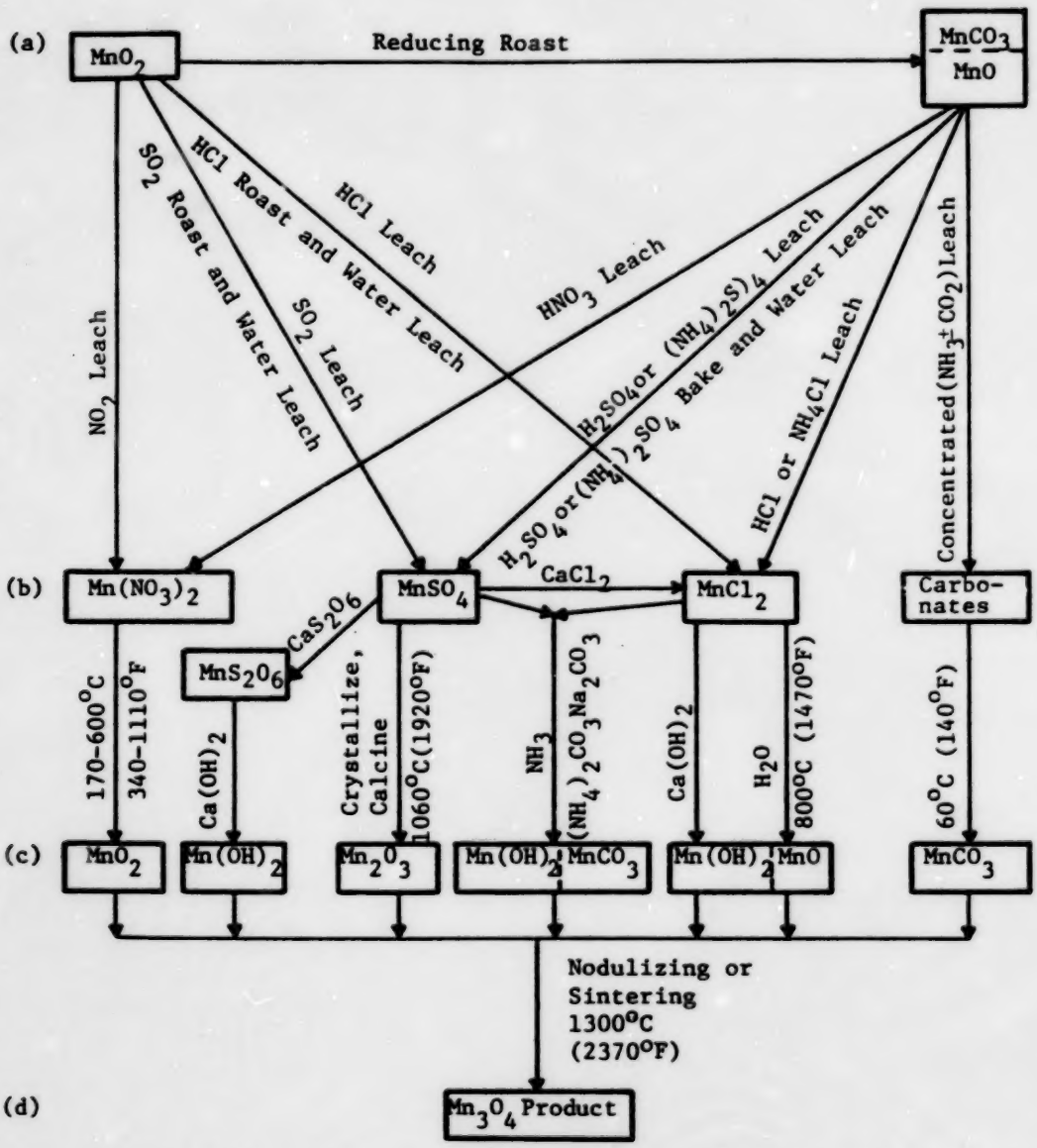
MARKET PRICES FOR DIFFERENT MANGANESE PRODUCTS

MANGANESE PRODUCT	PRICE/TONNE $C	SOURCE
Manganese Metal		
a) regular 99.5 %Mn	1851	(E&MJ. April 83)
b) 6% N, 93.7 %Mn	2111	(E&MJ. April 83)
Ferromanganese		
a) standard 78 %Mn	588	(E&MJ. April 83)
b) imported (F.o.b. Pittsburgh or Chicago)	402	(E&MJ. April 83)
Silicomanganese (16-18% Si, 2%C)	540	(E&MJ. April 83)
Manganese Ore (Min 48% Mn, low impurities)	1.9-2.0/ltu.	(E&MJ. April 83)
Manganese Dioxide (West African)		CHEM. MARKETING REPORTER
a) 74 - 76% MnO_2	264	April 11.83
b) 84% MnO_2	331-462	
Manganese Dioxide (synthetic)		CHEM. MARKETING REPORTER
(battery grade 90-92% MnO_2)	1851	April 11.83

TABLE 7

SELECTED CANADIAN LOW-GRADE MANGANESE ORE DEPOSITS (3)

LOCATION	Tonnes	Mn %	Fe %	SiO_2 %	Al_2O_3 %	CaO %	MgO %	S %	P %	REMARKS
NEW BRUNSWICK Woodstock	200 Million	14-16	20-22	20	3.5	3.8	1.5		1.0	Carbonate Silicate Ore
NEWFOUNDLAND Manuels River	10 Million	5-10	1-5	-	-	-	-	-	-	Carbonate
NEWFOUNDLAND Brigus Bay		22.1	4.9	23.2	13.8	1.2	1.8	0.18	0.06	-
ONTARIO Steep Rock		13.6	53.6	3.2	1.2	X?	X?	X?	0.2	-
QUEBEC Knob Lake		8-12	54-59	1.6-3.2	1.2-5.1	X?	X?	X?	0.01	-
NOVA SCOTIA O'Handly	200,000	10-40	10-25	-	-	-	-	-	-	Manganese Dioxide



NOTE: (a) Mn mineral (intermediate oxides may be considered to behave essentially like mixtures of MnO_2 and MnO).
(b) Solution.
(c) Product recovered from solution.
(d) Synthetic ferro-grade manganese ore.

FIGURE 1 Hydrometallurgy of Manganese. (4)

TABLE 8

COMPARISON OF PROCESSES FOR PRODUCING SYNTHETIC MnO_2 FROM MANGANESE ORES CONTAINING MANGANESE IN THE FORM OF MnO_2

PROCESSES AND PRODUCT RECOVERY STEPS	PRODUCT	CAPITAL COST	ENERGY COST	REAGENT COST	ENVIRONMENTAL COST
I Processes that can be applied directly to the ore					
1. NO_2 Leach-Calcination	MnO_2	high	high	high	high
2. SO_2 Leach					
a) Evaporation and calcination	Mn_2O_3	high	high	low	high
b) Precipitation with NH_3	$Mn(OH)_2$	high	high	low	high
c) Converting to $MnCl_2$ and precipitation with CaO	$Mn(OH)_2$	high	high	low	high
3. SO_2 Roast and Water Leach					
a) Evaporation and calcination	Mn_2O_3	medium	high	low	high
b) Precipitation with NH_3	$Mn(OH)_2$	high	high	high	high
c) Converting to $MnCl_2$ and precipitation with CaO	$Mn(OH)_2$	high	high	high	high
4. HCl Leach					
a) Precipitation with CaO	$Mn(OH)_7$	high	high	high	high
b) Calcination	MnO	high	high	high	
c) Precipitation with $(NH_4)_2CO_3$, Na_2CO_3	$MnCO_3$	high	high	high	

TABLE 8
(Cont'd)

COMPARISON OF PROCESSES FOR PRODUCING SYNTHETIC MnO_2 FROM MANGANESE ORES CONTAINING MANGANESE IN THE FORM OF MnO_2

PROCESSES AND PRODUCT RECOVERY STEPS	PRODUCT	CAPITAL COST	ENERGY COST	REAGENT COST	ENVIRONMENTAL COST
II **Processes that require reduced ore**					
1. HNO_3 Leach-Calcination	MnO_2	high	high	high	high
2. H_2SO_4 or $(NH_4)_2SO_4$ Leach					
a) Evaporation and calcination	Mn_2O_3	high	high	high	high
b) Precipitation with NH_3	$Mn(OH)_2$	high	high	high	high
c) Converting to $MnCl_2$ and precipitation with CaO	$Mn(OH)_2$	high	high	high	high
3. H_2SO_4 or $(NH_4)_2SO_4$ Bake and Water Leach					
a) Evaporation & calcination	Mn_2O_3	high	high	high	high
b) Precipitation with NH_3	$Mn(OH)_2$	high	high	high	high
c) Converting to $MnCl_2$ and precipitation with CaO	$Mn(OH)_2$	high	high	high	high
4. HCl or $(NH_4)Cl$ Leach					
a) Precipitation with CaO	$Mn(OH)_2$	high	high	high	high
b) Calcination	MnO	high	high	high	hgih
c) Precipitation with $(NH_4)_2CO_3$ or Na_2CO_3	$MnCo_3$	high	high	high	high
5. Concentrated (NH_3 + CO_2) Leach-Solution Heating	$MnCO_3$	high	high	high	high

The processes which are used to treat manganese ores that contain mainly $MnCO_3$ are identical to and have a similar rating as the group II processes shown in Table 8; the exception is that the ore need not be reduced before baking or leaching.

In Table 8, capital, energy, reagent and environmental costs are rated as high for nearly all the processes. The only process for which the capital and reagent costs are rated "moderate" and "low" respectively is the: "SO_2 Roast - Water Leach - Calcination Process".

A detailed capital and operating cost estimate was prepared for the SO_2 Roast - Water Leach - Calcination process, which, from now on will be referred to as the **"SULPHATIZATION PROCESS"** (5). A simplified flowsheet for the Sulphatization process is shown in Figure 2.

In the sulphatization process manganese ore is roasted in the presence of SO_2. Sulphur dioxide is provided by either burning elemental sulphur or mixing manganese ore with sulphur bearing material such as pyrite. The sulphatization roast is carried out at 600-850°C where manganese is selectively sulphatized. The calcine is then water leached to solubilize manganese sulphate. The main advantage of the process is that sulphatization is reasonably selective for manganese, so ore with a higher impurity level can be used, and corrosion problems in the leaching section are not as severe as in the case of the acid leach.

Capital and operating cost estimates for the process are shown on Tables 9 and 10 respectively. The capital cost for a 158 TPD sulphatization plant is estimated at $35.6 million with operating cost of $428 per tonne of synthetic MnO_2.

An examination of all the processes shown in Figure 1, indicated that the SO_2 Roast-Water Leach - Lime Neutralization process (from now on called Sulphatization - Lime Neutralization process) might be more economical than the Sulphatization process.

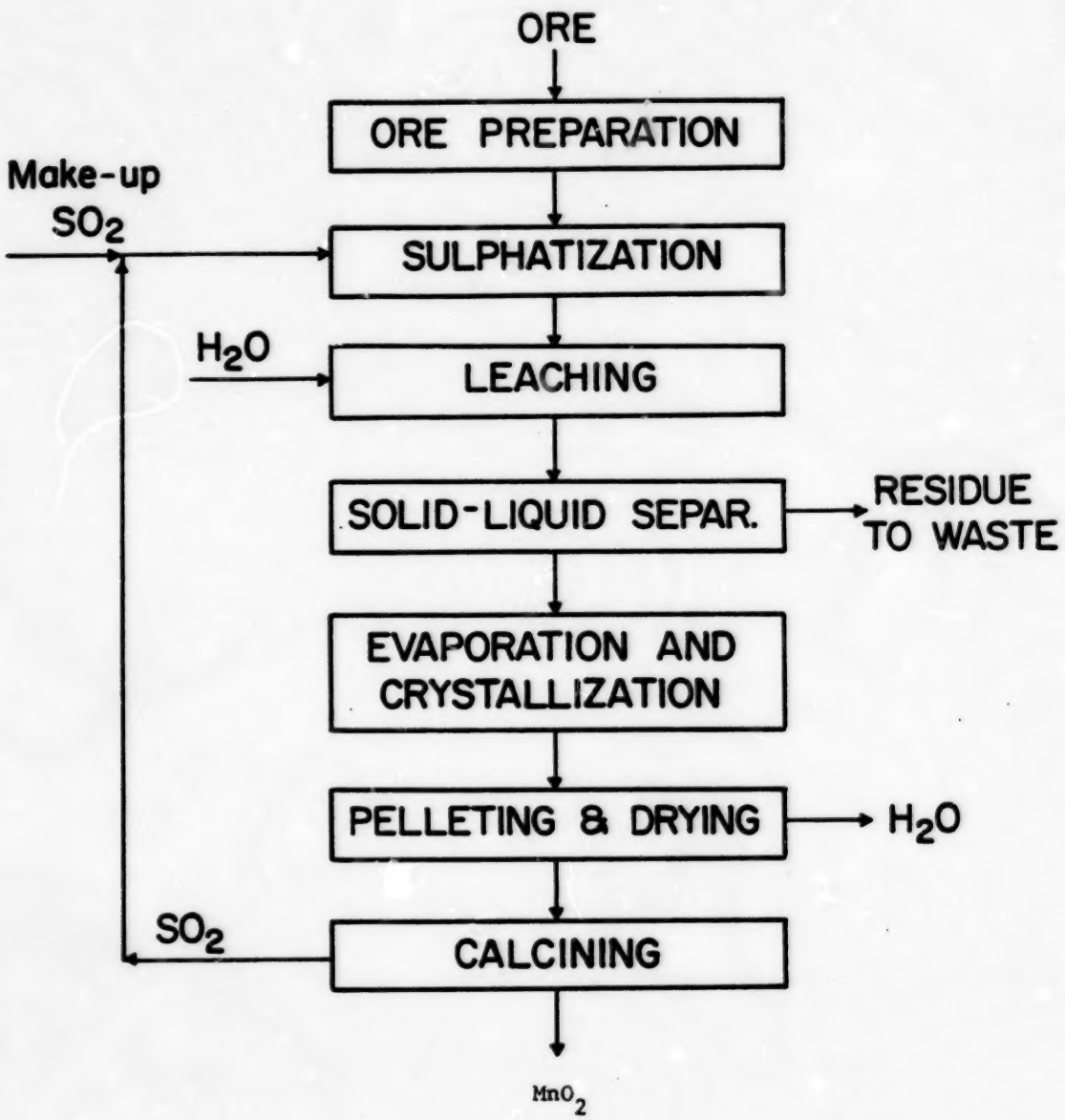


Figure 2 Sulphatization Process (without by-product recovery) for the Production of Synthetic MnO_2. (5)

TABLE 9

ESTIMATED CAPITAL COST, 158 TPD SULPHATIZATION PLANT (14% MANGANESE ORE, WOODSTOCK, N.B.)

Ore preparation section	6,370,843
Sulphatization section	951,978
Leaching section	2,298,900
Manganese product recovery (MnO_2)	9,782,109
Total section cost	**19,403,830**
Plant facilities 10% of total section cost	1,940,383
Plant utilities 12% of total section cost	2,328,460
Total physical cost	**23,672,673**
Engineering and construction fee 15% of total physical cost	3,550,901
Total direct cost	**27,223,574**
Contractor fee 5% of total direct cost	1,361,179
Contingency 10% of total direct cost	2,722,357
Total plant cost	**31,307,110**
Interest during plant construction	1,300,000
Fixed capital cost	**32,607,110**
Working capital	3,000,000
Total capital cost	**35,607,110**

TABLE 10

ESTIMATED OPERATING COST, 158 TPD SULPHATIZATION PLANT
(14% MANGANESE ORE, WOODSTOCK, N.B.)(5)

DIRECT COST	$ PER TONNE MnO_2
Raw Material:	
Ore at $14.0 per tonne	84.44
Lignite at $30.0 per tonne	2.84
Bentonite $90.0 per tonne	3.41
Sulphur $120.0 per tonne	7.59
Grinding rods $0.5 per kg	1.58
Grinding balls $0.6 per tonne	8.65
Total	**108.51**
Utilities:	
Electric power $0.03 per kwh	18.98
Water process $0.05 per m^3	4.31
Natural gas $3.78 per GJ	125.00
Total	**148.29**
Direct Labour:	
Labour at $11.0 per hour	56.60
Supervision 15% of labour	8.48
Total	**65.08**
Plant Maintenance:	
5% of total section cost	18.60
Operating Supply:	
15% of plant maintenance	2.79
TOTAL DIRECT COST	**343.27**
INDIRECT COST	
50% of direct labour and maintenance	41.84
FIXED COST	
Taxes and insurance 2% of total plant cost	12.00
Depreciation 5% of fixed capital cost	31.26
TOTAL OPERATING COST	**428.37**

A more detailed flowsheet for the Sulphatization - Lime Neutralization process is shown in Figure 3. The disadvantages of the process are:

1) it uses three solid-liquid separation stages which are capital intensive; and

2) the reagent $CaCl_2$ cannot be recycled directly to the system because it is too dilute.

Although recycling of the evaporated solution can be considered, the energy costs detract considerably from the attractiveness of the process.

Accordingly, a modified Sulphatization - Lime Neutralization process, as described below, should be considered.

MODIFIED SULPHATIZATION - LIME NEUTRALIZATION PROCESS

In the Modified Sulphatization - Lime Neutralization process (Figure 4), manganese ore is crushed, sized and pelletized. The pellets are fed to the sulphatizing furnace where the manganese reacts with sulphur dioxide to form manganese sulphate. The calcine is leached with a solution of $CaCl_2$ and the manganese sulphate is converted to manganese chloride and calcium sulphate according to the reaction:

$$MnSO_4 + CaCl_2 = MnCl_2 + CaSO_4$$

The slurry goes through a solid liquid separation process in which the gangue and $CaSO_4$ are separated from the $MnCl_2$ solution. The filtrate is then treated with lime and the $MnCl_2$ is converted to $Mn(OH)_2$ and $CaCl_2$. $Mn(OH)_2$ is filtered off and the solution of $CaCl_2$ is returned to the leaching circuit. The filter cake, containing mainly $Mn(OH)_2$, is dried and is then ready for further processing.

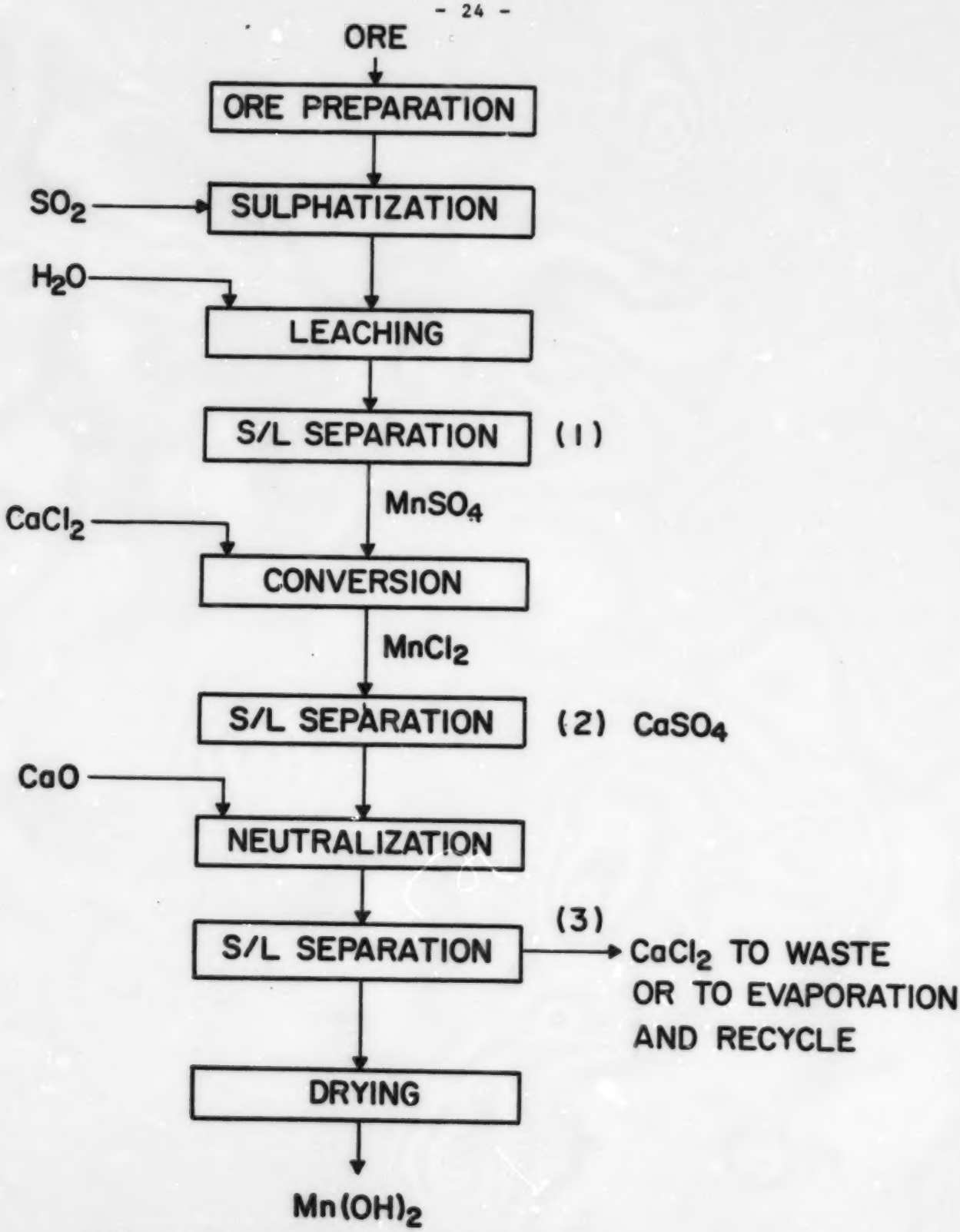
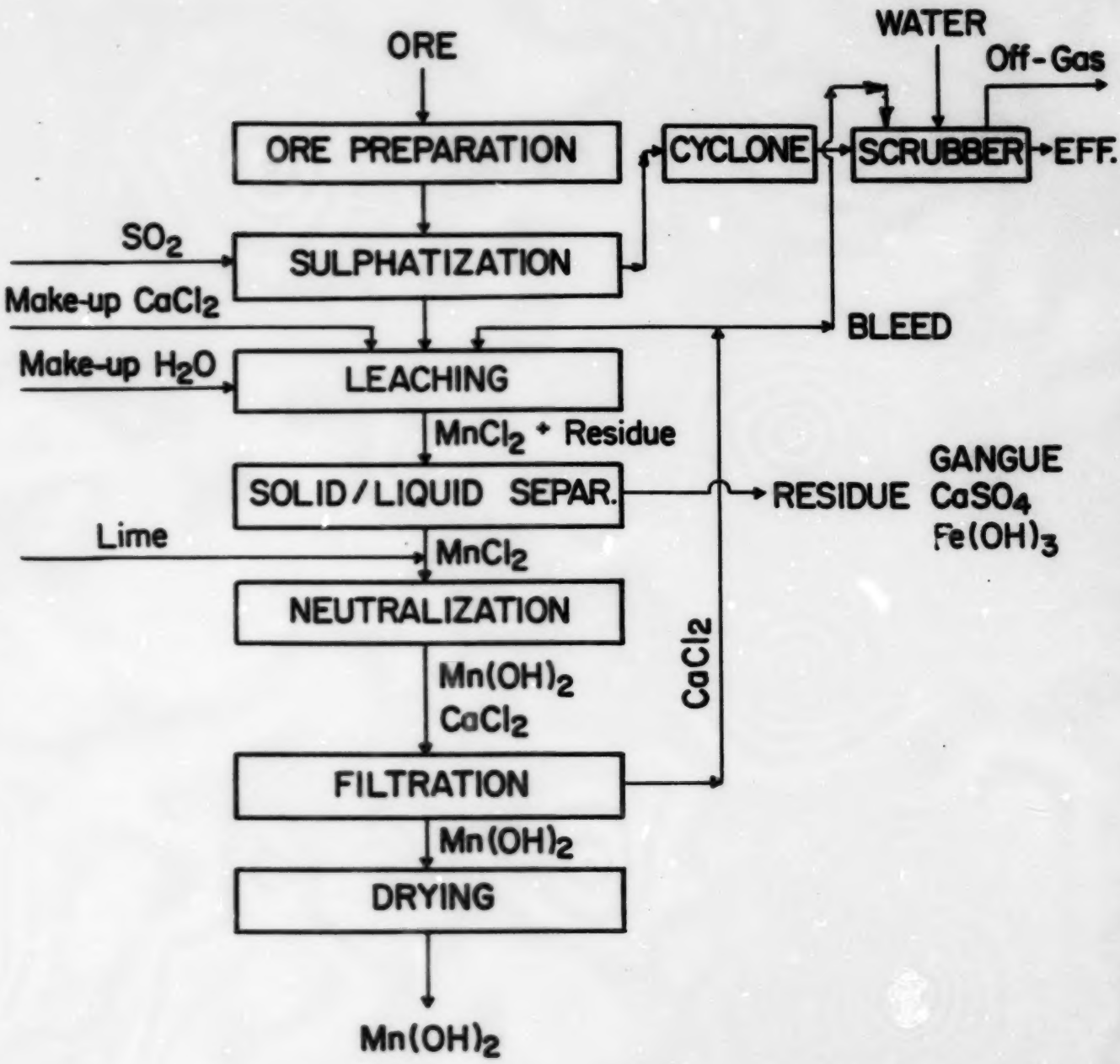


FIGURE 3 Sulphatization - Lime Neutralization Process for the Production of Synthetic $Mn(OH)_2$



For the manufacture of MnO_2 and other manganese compounds

FIGURE 4 Modified Sulphatization - Lime Neutralization Process for the Production of Synthetic $Mn(OH)_2$

Capital and operating cost estimates for a plant producing 158 TPD MnO_2 ($Mn(OH)_2$) from Woodstock, N.B. manganese ore containing 14% manganese are shown in Tables 11 and 12 respectively.

An examination of the cost of imported ores demonstrates how difficult it would be for MnO_2 material obtained from low-grade domestic ores to compete with imported ores containing 55 per cent MnO_2 now used for the domestic production of ferromanganese.

Commercially available manganese ore contains 55% Mn (equivalent to 86.9% MnO_2) and is sold for \$1.94-2.06 per unit (percent). Therefore one tonne of manganese ore costs 55 x 1.94 = \$107 plus \$25 for transport, for a total cost of \$132.0. If 100% MnO_2 (Mn content 63.1%) is produced by a chemical process, the highest possible price it could be sold for (based on its manganese content alone) for ferromanganese production is 63.1 x 2.06 = \$130. One tonne of synthetic ore would replace $\frac{63.1}{55}$ = 1.14 imported ore at a cost of 1.14 x 132 = \$151. Therefore the production cost of synthetic MnO_2 should not be very much higher than \$151 per tonne. With present energy prices none of the processes shown on Figure 1 are capable of producing MnO_2 for \$151 per tonne. The Modified Sulphatization - Lime Neutralization process, which is considered to be the least expensive process among all the processes can produce synthetic MnO_2 for \$371 per tonne (Table 12). Thus, even at \$355 per tonne, synthetic manganese dioxide cannot compete with imported manganese ore for the production of ferro- and silicomanganese alloys.

It is conceivable that the synthetic manganese dioxide produced by the Modified Sulphatization - Lime Neutralization process could replace some of the imported, naturally-occuring battery-grade manganese dioxide. Similarly synthetic managanese hydroxide could be the starting material for the production of other high priced manganese chemicals.

TABLE 11

ESTIMATED CAPITAL COST
158 TPD MODIFIED SULPHATIZATION - LIME NEUTRALIZATION PLANT (14% MANGANESE ORE, WOODSTOCK, N.B.)

Ore preparation section	6,381,347
Sulphatization section	1,472,829
Leaching section	2,298,506
Neutralization section	3,000,000
Total section cost	**13,152,682**
Plant facilities 10% of total section cost	1,315,268
Plant utilities 12% of total section cost	1,578,321
Total physical cost	**16,046,271**
Engineering and construction fee 15% of total physical cost	2,406,940
Total direct cost	**18,453,211**
Contractor fee 5% of total direct cost	922,660
	19,375,871
Contingency 10% of total direct cost	1,937,587
Total plant cost	**21,313,458**
Interest during plant construction	1,000,000
Fixed capital cost	**22,313,458**
Working capital	2,231,346
Total capital cost	**24,544,804**

TABLE 12

ESTIMATED OPERATING COST, 158 TPD MODIFIED SULPHATIZATION - LIME NEUTRALIZATION PLANT (14% MANGANESE ORE, WOODSTOCK, N.B.)

DIRECT COST	$ PER TONNE MnO_2
Raw Material:	
Ore at $14.0 per tonne	84.44
Lignite at $30.0 per tonne	2.84
Bentonite $90.0 per tonne	3.41
Sulphur $120.0 per tonne	55.44
Lime $42 per tonne	29.24
Calcium chloride $120 per tonne	3.79
Grinding rods $0.5 per kg	1.58
Grinding balls $0.6 per tonne	8.65
Total	**189.39**
Utilities:	
Electric power $0.03 per kwh	18.98
Water $0.05 per m^3	3.16
Natural gas $3.78 per GJ	21.51
Total	**43.65**
Direct Labour:	
Labour at $11.0 per hour	41.77
Supervision 15% of labour	6.26
Total	**48.03**
Plant Maintenance:	
5% of total section cost	12.51
Operating Supply:	
15% of plant maintenance	1.87
TOTAL DIRECT COST	**295.45**
INDIRECT COST	
50% of direct labour and maintenance	30.27
FIXED COST	
Taxes and insurance 2% of total plant cost	8.18
Depreciation 5% of fixed capital cost	21.29
TOTAL OPERATING COST	**355.19**

MANGANESE METAL AND BATTERY-GRADE MANGANESE DIOXIDE

Manganese metal and battery-grade manganese dioxide are high cost commodities. Their high cost is due, mainly, to the high energy and labour inputs required in their manufacture. Raw material cost has a less significant effect.

The import value of manganese metal (Table 2) was approximately $8.8 million in 1979 in comparison to the total import value of manganese ores of $8.4 million. The import of manganese ore, ferro- and silicomanganese fluctuates according to the state of the steel industry. Manganese metal and battery-grade manganese dioxide import (especially the latter) do not appear to be affected by up-turns and down-turns in steel production. Therefore the possibility of their domestic production should be examined not only for an emergency but for the present situation. Since raw material cost is relatively low even with imported material, in comparison with the total manufacturing cost, it might be possible to use domestic low-grade manganese ore to produce manganese metal and battery-grade manganese dioxide.

Manganese Metal

Two methods are currently used by industry for the production of manganese metal. Both processes use electrolysis. One process employs an aqueous solution while the other uses fused salt electrolysis. In this report only the aqueous solution process will be described.

Electrolysis of Aqueous Solution

Manganese ore or slag from ferromanganese production is crushed to less than $\frac{1}{4}$ inch and roasted to MnO, leaving as much of the iron as possible as Fe_3O_4, which is less soluble in dilute H_2SO_4 than are the lower oxides of iron. The reduced ore or slag is then leached with sulphuric acid. After solid-liquid separation the solution is neutralized with ammonia to precipitate iron and aluminum which are later removed by filtration. Other impurities, copper, zinc, lead etc., if present, are removed by hydrogen sulphide. The purified liquid containing $MnSO_4$ is electrolysed in a diaphram cell.

The successful electrolysis of manganese from very pure solutions of $MnSO_4$ plus $(NH_4)_2SO_4$ depends on cell design, solution concentration, pH, flow rate to cells, temperature, anode and cathode composition, and treatment of the cathode. The optimum conditions for electrowinning manganese are given in Table 13.

Manganese hydroxide formation occurs in the catholyte if the manganese content is greater than 14.5g/L; treeing and burning of the deposit is prevented by the addition of 0.10g/L SO_2.

Stripping of the cathode is important and is influenced by cathode surface treatment, gauge of cathode, manganese concentration in the cells, catholyte pH, smoothness of the deposit and cathode material. Since it is brittle the deposit is removed as chips by flexing or striking the cathode with a rubber mallet. The hydrogen in the metal can be removed by heating at 500°C.

Electrolytic Manganese Dioxide

The electrolyte can be prepared from either manganese carbonate (rhodochrosite) or manganese dioxide ore. Electrolyte preparation is similar to that described for manganese metal. Figure 5 is a simplified flowsheet for the process using MnO_2 or $MnCO_3$ as starting materials.

The production of electrolytic manganese dioxide essentially consists of five steps:

1) reduction of the ore,
2) leaching of the manganese,
3) purification of the manganese sulphate solution,
4) deposition of MnO_2 in electrolytic cells, and
5) preparation of finished MnO_2.

TABLE 13

ELECTROLYSIS OF MANGANESE SULPHATE (2)

CONDITION	VALUE
purified feed solution	
Mn as $MnSO_4$, g/L	30-40
$(NH_4)_2SO_4$, g/L	125-150
SO_2, g/L	0.30-0.50
anolyte	
Mn as $MnSO_4$, g/L	10-20
H_2SO_4, g/L	25-40
$(NH_4)_2SO_4$, g/L	125-150
current density, mA/cm^2	43-65
catholyte pH	6-7.2
anode composition	Pb + 1% Ag
cathode composition	Hastelloy, Type 316 stainless steel, or Ti
cell voltage, V	5.1
diaphragm	acrylic [a]
current efficiency, %	60-70
power consumption, kWh/kg	8-9

[a] Usually specified as to porosity.

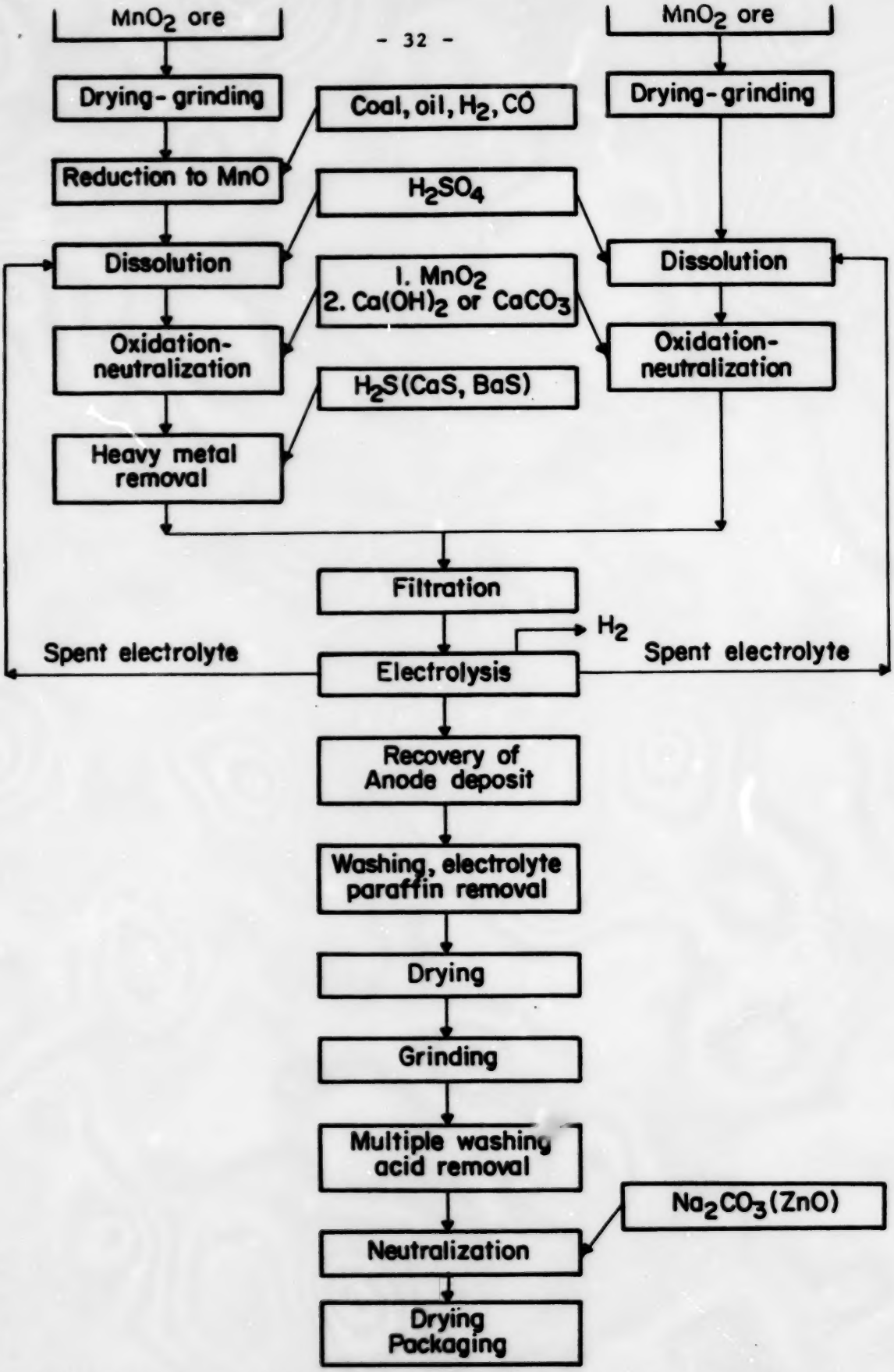


FIGURE 5 Sulphuric Acid Leach Process for the Production of Electrolytic Manganese Dioxide (EMD)

Manganese in the ground ore is reduced to the acid-soluble divalent state using oil, coal, coke or natural gas at 750°C in a rotary kiln. Manganese is leached from the calcine with spent electrolyte enriched with fresh sulphuric acid. The pH of the leach solution is maintained between 2.0-3.5. After leaching is completed, the pH is adjusted to 6.5-7.5 with lime or calcine to precipitate iron, aluminum and silica. After solid/liquid separation, the $MnSO_4$ solution is treated with H_2S or BaS to precipitate Zn, Cu, Co, Pb and Ni. Thus, a relatively pure solution containing about 150g/L $MnSO_4$ is fed to the electrolytic cell.

MnO_2 is plated on the anode in a diaphragmless cell in which the acid concentration is maintained constant by overflow of solution. Deposition of MnO_2 is generally continued until the deposit is 1 inch thick. If plate graphite or lead is used as an anode, the MnO_2 is stripped from the plate by hitting it with a hammer. If a rod anode is used, it is ground with the MnO_2. The typical conditions for an electrolytic cell to produce battery-grade MnO_2 are summarized in Table 14.

The MnO_2 is ground until 95% passes a No. 100 U.S. standard size. It is washed to remove sulphuric acid, manganese sulphate, and to bring the pH within a range of 4.0-7.0. The MnO_2 is then filtered and dried to about 1% moisture.

At the cathode, 1 mole of hydrogen gas is generated for each mole of MnO_2 formed at the anode. Thus a large EMD plant produces considerable quantities of hydrogen. Current efficiency in the electrolysis is as high as 90-95%. Electricity requirements per kg of EMD are about 0.45 kwh.[2]

TABLE 14

ELECTROLYSIS CONDITIONS FOR PRODUCING SYNTHETIC BATTERY-GRADE MnO_2 (2)

CONDITION	VALUE
Temperature	90-94°C
Anode Current Density	54-108 A/m^2
Anode-Cathode Spacing	1-2 inches
Acid Concentration	5-75g/L
Manganese Sulphate	50-100g/L
Voltage	2.2-2.6 volts
Cathode Current Density	27.0-108 A/m^2
Power Requirement	0.45 kwh/kg MnO_2
Heavy Metals and Iron Impurities in Solution	0.05%
Cathode	graphite
Anodes	graphite
Current Efficiency	90-95%

Comparison of Sulphuric Acid Leach with the Modified Sulphatization - Lime Neutralization Process to Produce Manganese and Battery-Grade Manganese Dioxide from Imported and Domestic Ores

Practically all the aqueous electrolytic manganese and manganese dioxide (EMD) plants in the world use a sulphuric acid leach for solution preparation. Low-grade domestic manganese ores could also be processed by the sulphuric acid process but at a much higher cost. The Modified Sulphatization - Lime Neutralization process, as was demonstrated in the production of synthetic manganese dioxide, might offer a less costly route for the production of electrolyte from low-grade domestic ore, than the sulphuric acid leach process.

In the following section, capital and operating cost estimates are presented for the above mentioned processes. The capital and operating cost estimates will be based on 10,000 tonnes of manganese plus 10,000 tonnes of MnO_2 (EMD). The domestic consumption, or import, of manganese metal and battery-grade manganese dioxide is around 8,000 and 3,000 tonnes/year respectively. (1)

a) **Sulphuric Acid Leach Process**

A simplified flowsheet for the Sulphuric Acid Leach process for the production of manganese metal and manganese dioxide from both domestic and imported ore is shown in Figure 6.

Capital and operating cost estimates for producing electrolyte, manganese metal and battery-grade manganese dioxide from imported and domestic ores are shown in Tables 15 to 18 and 19 to 22 respectively. Depreciation is based on 20 year straight line. The capital cost of 30 TPD electrolysis plants for either manganese metal or battery-grade manganese dioxide (EMD) is estimated at $13 million. No credit is allowed for the by-product H_2 formed during electrolysis.

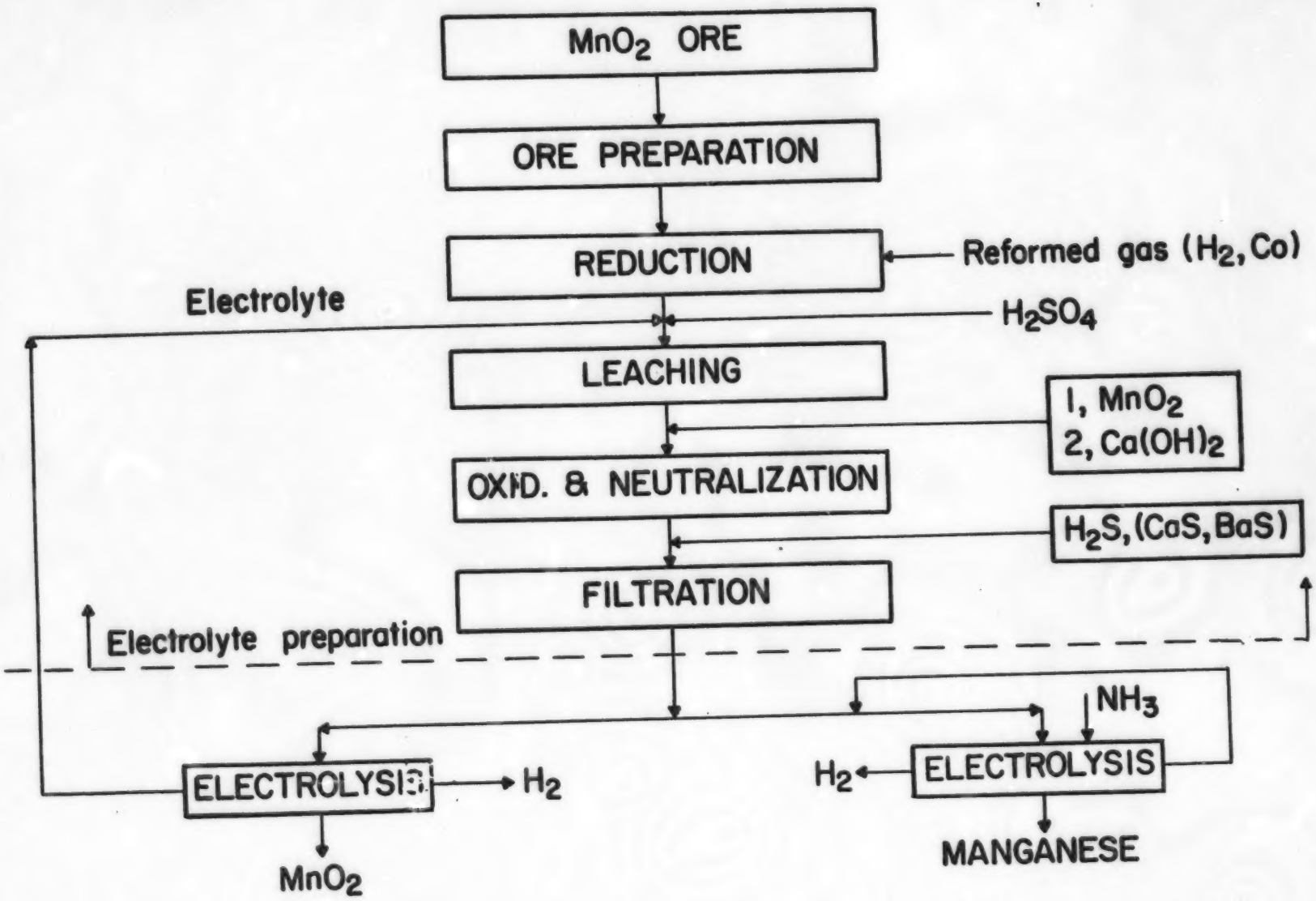


FIGURE 6 Sulphuric Acid Leach Process for the Production of Electrolytic Manganese and Manganese Dioxide (EMD)

TABLE 15

ESTIMATED CAPITAL COST, 50 TPD SULPHURIC ACID LEACH PLANT (54% IMPORTED MANGANESE ORE)

	$
Ore preparation section	245,008
Reduction section	446,541
Leaching section	5,681,843
Solution purification section	1,901,369
Steam plant	2,382,377
Total section cost	**10,657,138**
Plant facilities 10% of total section cost	1,065,713
Plant utilities 12% of total section cost	1,278,856
Total physical cost	**13,001,707**
Engineering and construction fee 15% of total physical cost	1,950,256
Total direct cost	**14,951,963**
Contractor fee 5% of total direct cost	747,598
Contingency 10% of total direct cost	1,495,196
Total plant cost	**17,194,757**
Interest during plant construction	1,200,000
Fixed capital cost	**18,394,757**
Working capital	1,500,000
Total capital cost	**19,894,757**

TABLE 16

OPERATING COST ESTIMATE, 50 TPD SULPHURIC ACID LEACH PLANT
(54% IMPORTED MANGANESE ORE)

DIRECT COST	$ PER TONNE CONTAINED MANGANESE
Raw Material:	
Ore at $132.0 per tonne	286.44
Lignite at $30.0 per tonne	1.20
Bentonite $90.0 per tonne	1.80
Sulphuric Acid $60.0 per tonne	6.00
Lime $42 per tonne	4.20
Grinding rods $0.5 per kg	0.50
Grinding balls $0.6 per tonne	3.6
Chemicals for steam plant	2.00
Total	**305.74**
Utilities:	
Electric power $0.03 per kwh	15.00
Water $0.05 per m^3	5.00
Natural gas $3.78 per GJ	64.00
Total	**84.00**
Direct Labour:	
Labour at $11.0 per hour	44.00
Supervision 15% of labour	6.60
Total	**50.60**
Plant Maintenance:	
5% of total section cost	32.63
Operating Supply:	
15% of plant maintenance	4.89
TOTAL DIRECT COST	**477.86**
INDIRECT COST	
50% of direct labour and maintenance	41.61
FIXED COST	
Taxes and insurance 2% of total plant cost	21.05
Depreciation 5% of fixed capital cost	52.61
TOTAL OPERATING COST	**593.13**

TABLE 17

OPERATING COST ESTIMATE, 30 TPD MANGANESE PLANT
(54% IMPORTED MANGANESE ORE)

DIRECT COST	$ PER TONNE MANGANESE
Raw Material:	
Purified solution	593.13
Ammonia $160/tonne	5.00
Anodes (estimate only)	5.00
Cathodes (estimate only)	10.00
Total	**613.13**
Utilities:	
Electricity $0.03 per kwh	270.00
Water $0.05/$m^3$	3.00
Total	**273.00**
Direct Labour:	
Labour at $11.0 per hour	55.00
Supervision 15% of labour	8.25
Total	**63.25**
Plant Maintenance:	
5% of total section cost	65.16
Operating Supply:	
15% of plant maintenance	9.77
TOTAL DIRECT COST	**1,024.31**
INDIRECT COST	
50% of direct labour and maintenance	64.20
FIXED COST	
Taxes and insurance 2% of total plant cost	22.15
Depreciation 5% of fixed capital cost	59.95
TOTAL OPERATING COST	**1,170.61**

TABLE 18

OPERATING COST ESTIMATE, 30 TPD MANGANESE DIOXIDE (EMD) PLANT (54% IMPORTED MANGANESE ORE)

DIRECT COST	**$ PER TONNE MnO_2 (EMD)**
Raw Material:	
Purified solution	375.39
Anodes (estimate only)	10.00
Cathodes (estimate only)	5.00
Total	**390.39**
Utilities:	
Electricity $0.03 per kwh	18.00
Water $0.05/$m^3$	3.00
Total	**21.00**
Direct Labour:	
Labour at $11.0 per hour	55.00
Supervision 15% of labour	8.25
Total	**63.25**
Plant Maintenance:	
5% of total section cost	65.16
Operating Supply:	
15% of plant maintenance	9.77
TOTAL DIRECT COST	**549.57**
INDIRECT COST	
50% of direct labour and maintenance	64.20
FIXED COST	
Taxes and insurance 2% of total plant cost	22.15
Depreciation 5% of fixed capital cost	59.95
TOTAL OPERATING COST	**695.87**

TABLE 19

ESTIMATED CAPITAL COST, 50 TPD SULPHURIC ACID LEACH PLANT (14% MANGANESE ORE, WOODSTOCK, N.B.)

	$
Ore preparation section	1,438,104
Reduction section	1,080,885
Leaching section	13,750,060
Solution purification section	1,901,369
Steam plant	2,382,375
Total section cost	**20,552,793**
Plant facilities 10% of total section cost	2,055,279
Plant utilities 12% of total section cost	2,466,335
Total physical cost	**25,074,407**
Engineering and Construction fee 15% of total physical cost	3,761,161
Total direct cost	**28,835,568**
Contractor fee 5% of total direct cost	1,441,778
Contingency 10% of total direct cost	2,835,568
Total plant cost	**33,112,914**
Interest during plant construction	2,500,000
Fixed capital cost	**35,612,914**
Working capital	3,000,000
Total capital cost	**38,612,914**

TABLE 20

OPERATING COST ESTIMATE, 50 TPD SULPHURIC ACID LEACH PLANT (14% MANGANESE ORE, WOODSTOCK, N.B.)

DIRECT COST	$ PER TONNE CONTAINED MANGANESE
Raw Material:	
Ore at $14.0 per tonne	133.42
Lignite at $30.0 per tonne	4.50
Bentonite $90.0 per tonne	5.40
Sulphuric Acid $60.0 per tonne	23.52
Lime $42 per tonne	83.40
Grinding rods $0.5 per kg	23.52
Grinding balls $0.6 per tonne	2.50
Chemicals for steam plant	13.68
	2.00
Total	**291.94**
Utilities:	
Electric power $0.03 per kwh	30.00
Water $0.05 per m^3	5.00
Natural gas $3.78 per GJ	72.00
Total	**107.00**
Direct Labour:	
Labour at $11.0 per hour	77.00
Supervision 15% of labour	11.50
Total	**88.50**
Plant Maintenance:	
5% of total section cost	62.93
Operating Supply:	
15% of plant maintenance	9.43
TOTAL DIRECT COST	**559.80**
INDIRECT COST	
50% of direct labour and maintenance	75.71
FIXED COST	
Taxes and insurance 2% of total plant cost	40.55
Depreciation 5% of fixed capital cost	109.04
TOTAL OPERATING COST	**785.10**

TABLE 21

OPERATING COST ESTIMATE, 30 TPD MANGANESE PLANT (14% MANGANESE ORE, WOODSTOCK, N.B.)

DIRECT COST	**$ PER TONNE MANGANESE**
Raw Material:	
Purified solution	785.10
Ammonia $160/tonne	5.00
Anodes (estimate only)	5.00
Cathodes (estimate only)	10.00
Total	**805.10**
Utilities:	
Electricity $0.03 per kwh	270.00
Water $0.05/$m^3$	3.00
Total	**273.00**
Direct Labour:	
Labour at $11.0 per hour	55.00
Supervision 15% of labour	8.25
Total	**63.25**
Plant Maintenance:	
5% of total section cost	65.16
Operating Supply:	
15% of plant maintenance	9.77
TOTAL DIRECT COST	**1,216.28**
INDIRECT COST	
50% of direct labour and maintenance	64.20
FIXED COST	
Taxes and insurance 2% of total plant cost	22.15
Depreciation 5% of fixed capital cost	59.95
TOTAL OPERATING COST	**1,362.58**

TABLE 22

OPERATING COST ESTIMATE, 30 TPD MANGANESE DIOXIDE (EMD) PLANT (14% MANGANESE ORE, WOODSTOCK, N.B.)

DIRECT COST	**$ PER TONNE MnO_2 (EMD)**
Raw Material:	
Purified solution	495.00
Anodes (estimate only)	10.00
Cathods (estimate only)	5.00
Total	**510.00**
Utilities:	
Electricity $0.03 per kwh	18.00
Water $0.05/$m^3$	3.00
Total	**21.00**
Direct Labour:	
Labour at $11.0 per hour	55.00
Supervision 15% of labour	8.25
Total	**63.25**
Plant Maintenance:	
5% of total section cost	65.16
Operating Supply:	
15% of plant maintenance	9.77
TOTAL DIRECT COST	**669.18**
INDIRECT COST	
50% of direct labour and maintenance	64.20
FIXED COST	
Taxes and insurance 2% of total plant cost	22.15
Depreciation 5% of fixed capital cost	59.95
TOTAL OPERATING COST	**815.48**

b) **Modified Sulphatization - Lime Neutralization Process**

The Modified Sulphatization - Lime Neutralization process can be used to extract manganese values from imported and domestic ores. The end product is acid soluble manganese hydroxide which is readily soluble in the electrolyte containing sulphuric acid. Figure 7 is a flowsheet for the Modified Sulphatization - Lime Neutralization process for electrolyte preparation and for the production of manganese and manganese dioxide by electrolysis. The flowsheet is applicable for both domestic and imported manganese ore.

Capital and operating cost estimates for the Modified Sulphatization - Lime Neutralization process, to produce electrolytic manganese and battery-grade manganese dioxide are shown as follows:

1. Domestic ore

   a) Modified Sulphatization - Lime Neturalization process for electrolyte preparation: Table 23 and 24
   b) Manganese metal: Table 25
   c) Battery-grade manganese dioxide: Table 26

2. Imported Ore

   a) Modified Sulphatization - Lime Neutralization process for electrolyte preparation: Table 27 and 28
   b) Manganese metal: Table 29
   c) Manganese dioxide: Table 30

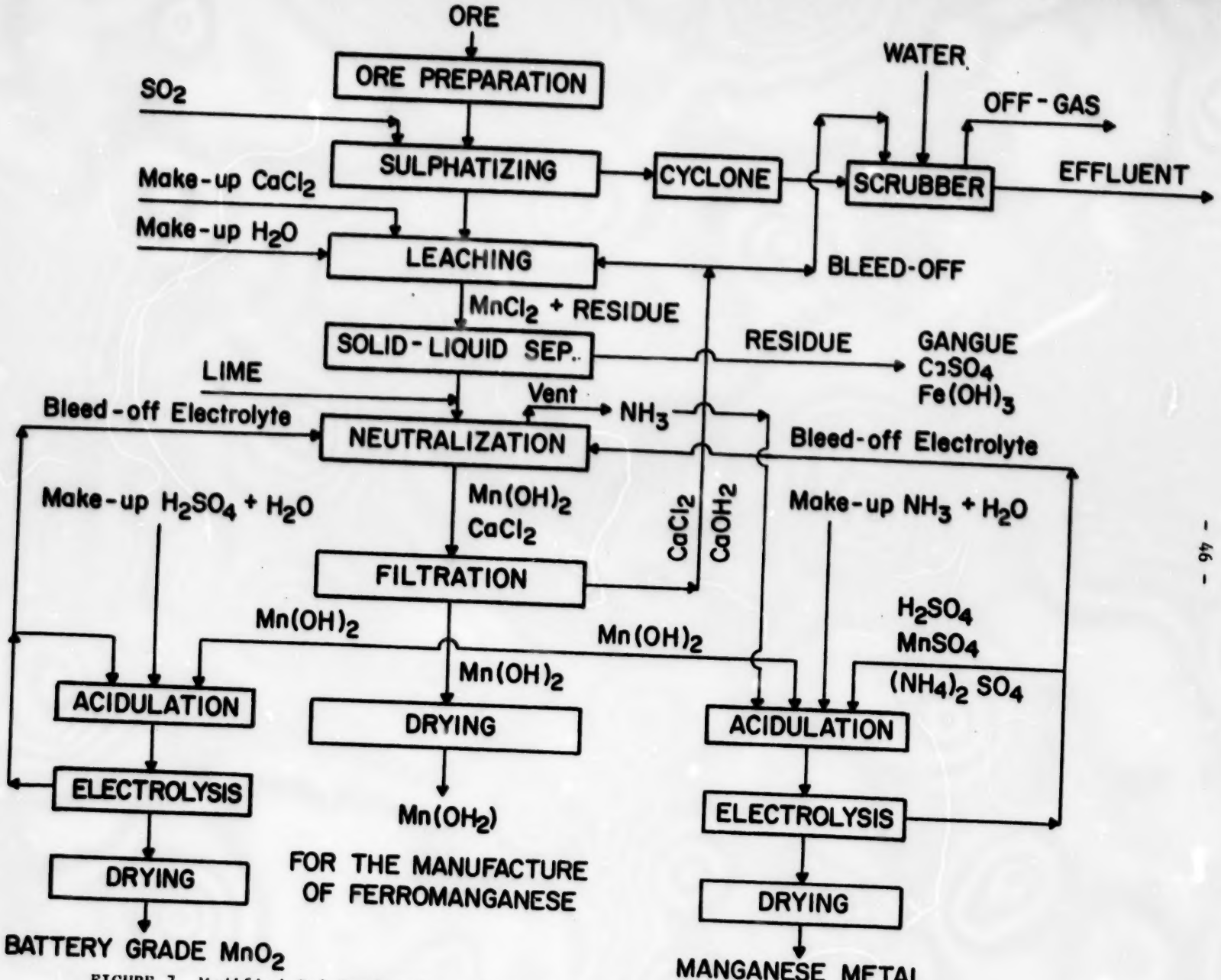


FIGURE 7 Modified Sulphatization - Lime Neutralization Process for the Production of Electrolytic Manganese and Manganese Dioxide

TABLE 23

ESTIMATED CAPITAL COST, 50 TPD MODIFIED SULPHATIZATION - LIME NEUTRALIZATION PLANT (14% MANGANESE ORE, WOODSTOCK N.B.)

	$
Ore preparation section	4,198,255
Sulphatization section	968,966
Leaching section	1,512,175
Neutralization section	1,973,684
Total section cost	**8,653,080**
Plant facilities 10% of total section cost	865,309
Plant utilities 12% of total section cost	1,038,370
Total physical cost	**10,556,759**
Engineering and Construction fee 15% of total physical cost	1,583,514
Total direct cost	**12,140,273**
Contractor fee 5% of total direct cost	607,014
Contingency 10% of total direct cost	1,214,027
Total plant cost	**13,961,314**
Interest during plant construction	657,895
Fixed capital cost	**14,619,209**
Working capital	1,467,991
Total capital cost	**16,087,200**

TABLE 24

ESTIMATED OPERATING COST, 50 TPD MODIFIED SULPHATIZATION - LIME NEUTRALIZATION PLANT (14% MANGANESE ORE, WOODSTOCK, N.B.)

DIRECT COST	$ PER TONNE CONTAINED MANGANESE
Raw Material:	
Ore at $14.0 per tonne	133.42
Lignite at $30.0 per tonne	4.50
Bentonite $90.0 per tonne	5.40
Sulphur $120.0 per tonne	87.60
Lime $42 per tonne	46.20
Calcium chloride $120 per tonne	6.00
Grinding rods $0.5 per kg	2.50
Grinding balls $0.6 per tonne	13.68
Total	**299.30**
Utilities:	
Electric power $0.03 per kwh	30.00
Water $0.05 per m^3	5.00
Natural gas $3.78 per GJ	34.00
Total	**69.00**
Direct Labour:	
Labour at $11.0 per hour	66.00
Supervision 15% of labour	9.90
Total	**75.90**
Plant Maintenance:	
5% of total section cost	26.49
Operating Supply:	
15% of plant maintenance	3.97
TOTAL DIRECT COST	**474.66**
INDIRECT COST	
50% of direct labour and maintenance	51.19
FIXED COST	
Taxes and insurance 2% of total plant cost	16.84
Depreciation 5% of fixed capital cost	43.62
TOTAL OPERATING COST	**586.31**

TABLE 25

OPERATING COST ESTIMATE, 30 TPD MANGANESE PLANT
(14% MANGANESE ORE, WOODSTOCK, N.B.)

DIRECT COST	$ PER TONNE MANGANESE
Raw Material:	
Purified solution	586.31
Anodes (estimate only)	10.00
Cathods (estimate only)	5.00
Total	**601.31**
Utilities:	
Electricity $0.03 per kwh	270.00
Water $0.05/$m^3$	3.00
Total	**273.00**
Direct Labour:	
Labour at $11.0 per hour	55.00
Supervision 15% of labour	8.25
Total	**63.25**
Plant Maintenance:	
5% of total section cost	65.16
Operating Supply:	
15% of plant maintenance	9.77
TOTAL DIRECT COST	**1,012.49**
INDIRECT COST	
50% of direct labour and maintenance	64.20
FIXED COST	
Taxes and insurance 2% of total plant cost	22.15
Depreciation 5% of fixed capital cost	59.95
TOTAL OPERATING COST	**1,158.79**

TABLE 26

OPERATING COST ESTIMATE, 30 TPD MANGANESE DIOXIDE (EMD) PLANT (14% MANGANESE ORE, WOODSTOCK, N.B.)

DIRECT COST	**$ PER TONNE MnO_2 (EMD)**
Raw Material:	
Purified solution	371.00
Anodes (estimate only)	10.00
Cathods (estimate only)	5.00
Total	**386.00**
Utilities:	
Electricity $0.03 per kwh	18.00
Water $0.05/$m^3$	3.00
Total	**21.00**
Direct Labour:	
Labour at $11.0 per hour	55.00
Supervision 15% of labour	8.25
Total	**63.25**
Plant Maintenance:	
5% of total section cost	65.16
Operating Supply:	
15% of plant maintenance	9.77
TOTAL DIRECT COST	**545.18**
INDIRECT COST	
50% of direct labour and maintenance	64.20
FIXED COST	
Taxes and insurance 2% of total plant cost	22.15
Depreciation 5% of fixed capital cost	59.95
TOTAL OPERATING COST	**691.48**

TABLE 27

ESTIMATED CAPITAL COST, 50 TPD MODIFIED SULPHATIZATION - LIME NEUTRALIZATION PLANT (54% IMPORTED MANGANESE ORE)

	$
Ore preparation section	1,719,638
Sulphatization section	398,788
Leaching section	622,459
Neutralization section	185,185
Total section cost	**2,926,070**
Plant facilities 10% of total section cost	292,607
Plant utilities 12% of total section cost	351,128
Total physical cost	**3,569,805**
Engineering and Construction fee 15% of total physical cost	535,471
Total direct cost	**4,105,276**
Contractor fee 5% of total direct cost	205,264
Contingency 10% of total direct cost	410,527
Total plant cost	**4,721,067**
Interest during plant construction	400,000
Fixed capital cost	**5,121,067**
Working capital	1,500,000
Total capital cost	**6,621,067**

TABLE 28

OPERATING COST ESTIMATE, 50 TPD MODIFIED SULPHATIZATION - LIME NEUTRALIZATION PLANT (54% IMPORTED MANGANESE ORE)

DIRECT COST	$ PER TONNE CONTAINED MANGANESE
Raw Material:	
Ore at $132. per tonne	282.48
Lignite at $30.0 per tonne	1.50
Bentonite $90.0 per tonne	1.80
Sulphur $120.0 per tonne	60.00
Lime $42 per tonne	35.00
Calcium chloride $120 per tonne	3.00
Grinding rods $0.5 per kg	0.80
Grinding balls $0.6 per tonne	4.00
Total	**388.58**
Utilities:	
Electric power $0.03 per kwh	10.00
Water $0.05 per m^3	5.00
Natural gas $3.78 per GJ	11.00
Total	**26.00**
Direct Labour:	
Labour at $11.0 per hour	44.00
Supervision 15% of labour	6.00
Total	**50.60**
Plant Maintenance:	
5% of total section cost	8.86
Operating Supply:	
15% of plant maintenance	1.32
TOTAL DIRECT COST	**475.36**
INDIRECT COST	
50% of direct labour and maintenance	29.73
FIXED COST	
Taxes and insurance 2% of total plant cost	5.72
Depreciation 5% of fixed capital cost	15.51
TOTAL OPERATING COST	**526.32**

TABLE 29

OPERATING COST ESTIMATE, 30 TPD ELECTROLYTIC MANGANESE PLANT
(54% IMPORTED MANGANESE ORE)

DIRECT COST	$ PER TONNE MANGANESE
Raw Materials:	
Purified solution	526.00
Ammonia $160/tonne	5.00
Anodes (estimate only)	5.00
Cathodes (estimate only)	10.00
Total	**546.00**
Utilities:	
Electricity $0.03 per kwh	270.00
Water $0.05/$m^3$	3.00
Total	**273.00**
Direct Labour:	
Labour at $11.0 per hour	55.00
Supervision 15% of labour	8.25
Total	**63.25**
Plant Maintenance:	
5% of total section cost	65.16
Operating Supply:	
15% of plant maintenance	9.77
TOTAL DIRECT COST	**957.18**
INDIRECT COST	
50% of direct labour and maintenance	64.20
FIXED COST	
Taxes and insurance 2% of total plant cost	22.15
Depreciation 5% of fixed capital cost	59.95
TOTAL OPERATING COST	**1,103.48**

TABLE 30

OPERATING COST ESTIMATE, 30 TPD MANGANESE DIOXIDE (EMD) PLANT (54% IMPORTED MANGANESE ORE)

DIRECT COST	**$ PER TONNE MnO_2 (EMD)**
Raw Material:	
Purified solution	332.27
Anodes (estimate only)	10.00
Cathodes (estimate only)	5.00
Total	**347.27**
Utilities:	
Electricity $0.03 per kwh	18.00
Water $0.05/$m^3$	3.00
Total	**21.00**
Direct Labour:	
Labour at $11.0 per hour	55.00
Supervision 15% of labour	8.25
Total	**63.25**
Plant Maintenance:	
5% of total section cost	65.16
Operating Supply:	
15% of plant maintenance	9.77
TOTAL DIRECT COST	**506.45**
INDIRECT COST	
50% of direct labour and maintenance	64.20
FIXED COST	
Taxes and insurance 2% of total plant cost	22.15
Depreciation 5% of fixed capital cost	59.95
TOTAL OPERATING COST	**652.75**

A summary of capital and operating cost estimates for the Sulphuric Acid leach, Modified Sulphatization - Lime Neutralization processes and for the manufacture of manganese metal and battery-grade manganese dioxide from imported and domestic manganese ore is shown in Table 31.

DISCUSSION

Table 31 shows that the Sulphuric Acid leach process is more expensive than the Modified Sulphatization - Lime Neutralization process to produce electrolyte, or feed material, for the manufacture of manganese metal and battery-grade manganese dioxide. Domestic manganese ore with the Modified Sulphatization - Lime Neutralization process appears to be competitive with imported ore, even with the high cost ($14/tonne) of ore assumed in the calculation. Manganese hydroxide produced by the Modified Sulphatization - Lime-Neutralization process could also be the starting material for the production of other manganese products such as $MnCl_2$, $MnSO_4$ and potassium permanganate and manganese carbide.

CONCLUSION

Extracting manganese values from domestic, low-grade manganese ore for the production of ferromanganese would not be economic. Producing ferromanganese from concentrate, extracted from domestic ores, would cost twice as much as from imported ores.

The production of manganese metal and battery-grade manganese dioxide from domestic and imported ores, with the Modified Sulphatization - Lime Neutralization process, appears to be economically viable.

Although capital and operating cost estimates for the production of different manganese products from domestic sources are based on the Woodstock, N.B. ore, the process recommended is equally applicable to manganese ores found in other provinces. The capital and operating costs would differ from ore to ore depending mainly on the manganese content of the ore.

TABLE 31

SUMMARY OF CAPITAL AND OPERATION COST ESTIMATES FOR PRODUCING MANAGANESE METAL AND BATTERY-GRADE MANGANESE DIOXIDE FROM DOMESTIC AND IMPORTED ORES

RAW MATERIALS AND PROCESSES	Electrolyte Preparation (or Synthetic $Mn(OH)_2$ Production) (16,500 TPY Mn Content)		Manganese Metal(1) (10,000 TPY Plant)		Battery-Grade Manganese Dioxide(2) (10,000 TPY MnO_2)	
	Cap. Cost $X10^6	Operat. Cost $/Tonne	Cap. Cost $X10^6	Operat. Cost $/Tonne	Cap. Cost $X10^6	Operat. Cost $/Tonne MnO_2
DOMESTIC ORE (Woodstock N.B.)						
1) Sulphuric Acid Leach	38.6	785.0	13.0	1,363.0	13.0	815.0
2) Modified Sulphatization - Lime Neutralization	16.1	586.0	13.0	1,159.0	13.0	691.0
IMPORTED ORE						
1) Sulphuric Acid Leach	19.8	593.0	13.0	1,171.0	13.0	696.0
2) Modified Sulphatization - Lime Neutralization	6.6	526.0	13.0	1,103.0	13.0	653.0

RECOMMENDATIONS

Since manganese metal and battery-grade manganese dioxide (both naturally occurring and electrolytically produced), are imported to Canada, the possibility of producing these commodities domestically should be examined.

At present, there is no research program at CANMET related to the extraction of manganese from domestic ores. It is therefore recommended that a research program be initiated to extract manganese from domestic sources using the Modified Sulphatization - Lime Neutralization process for the production of manganese and battery-grade manganese dioxide.

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